VNIVERSITAT DE VALÈNCIA Facultat de Magisteri

Natural sciences for schoolteachers
LESSON 5:
Earth, a changing planet

Contents

Planet formation

Earth

Earth is a planet of the **solar system** that revolves around the **Sun**.

Image: NASA

Earth is the third planet from the Sun. It is the densest and the fifth largest planet in the solar system.

Planet formation

Formation of the universe

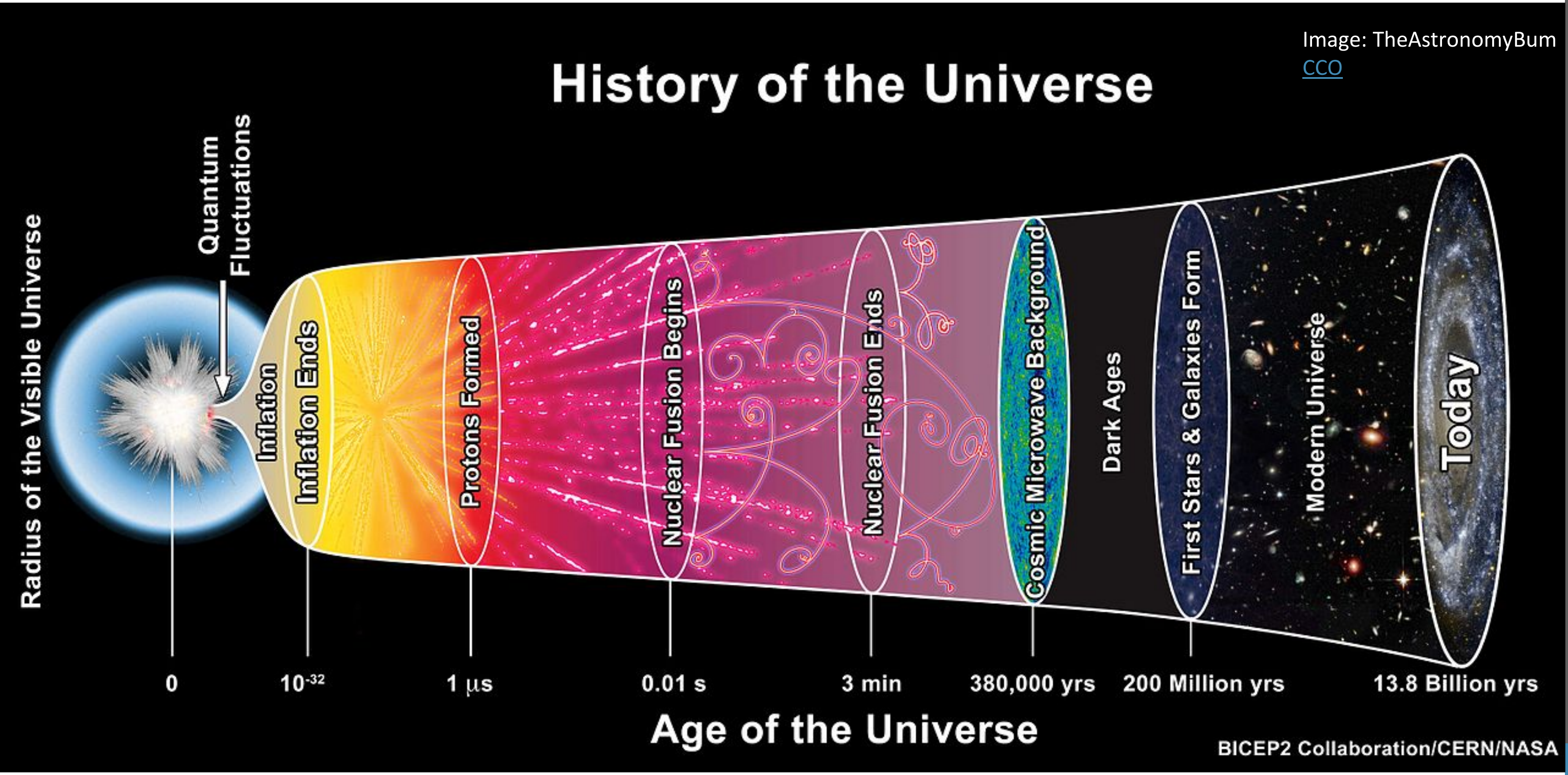


Image: TheAstronomyBum
CCO

Planet formation

Formation of the universe

The **Big Bang theory** describes how the **universe** (time, space, and matter) began **~13 800 million years ago** with the explosion of a ***singularity***, which was extremely dense and hot.

After the initial expansion, which still continues today, the universe cooled enough to allow the formation of **subatomic particles**. These particles later grouped together forming simple **atoms**.

Giant clouds of these primordial elements coalesced through gravity, eventually forming the first **stars** and **galaxies**. The first stars created heavier atoms, which led to more stars being born, as well as other objects such as asteroids, comets, planets, black holes, etc.

Planet formation

Formation of the solar system

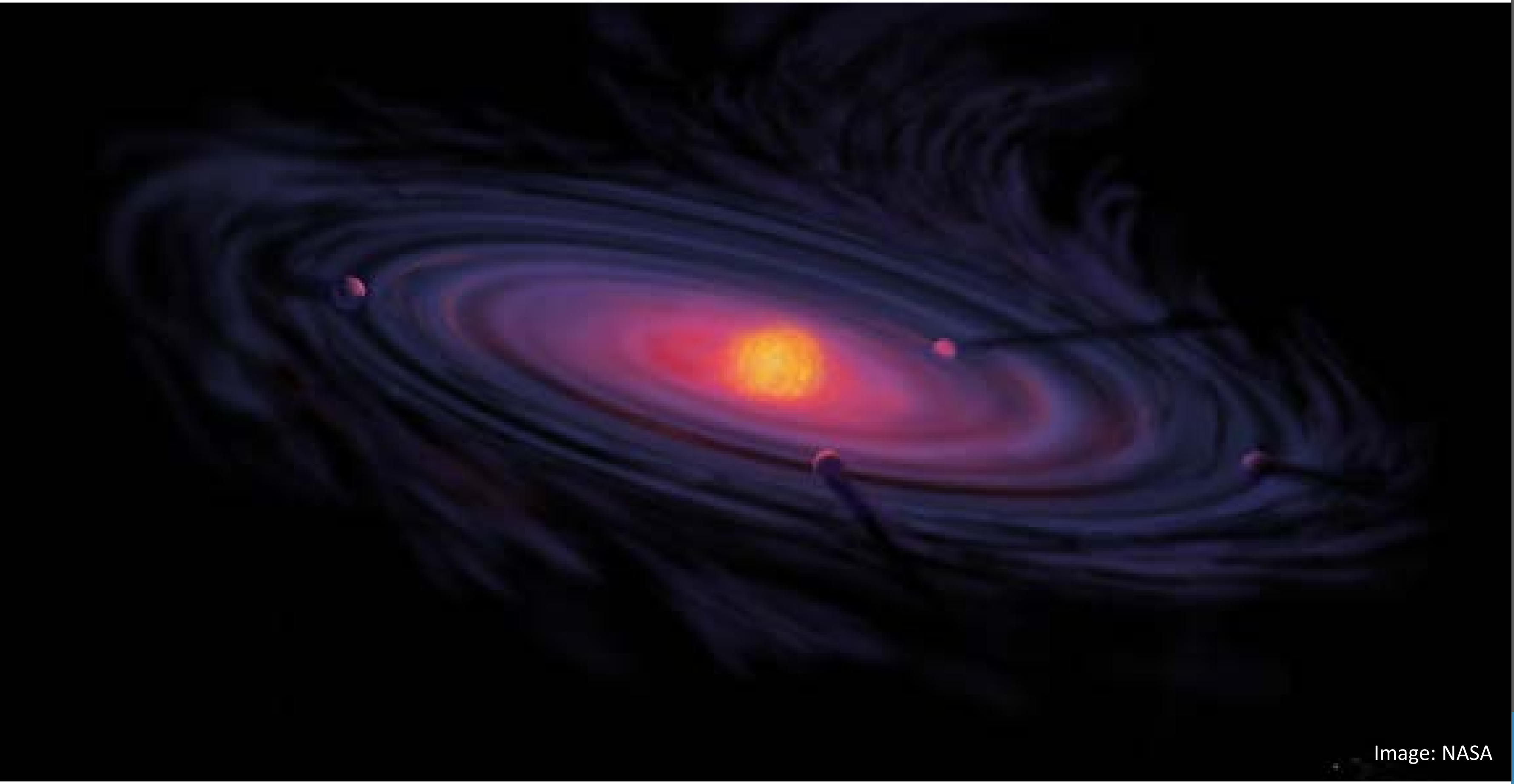


Image: NASA

Planet formation

Formation of the solar system

The **solar system** formed **~4 600 million years ago** from a large **interstellar cloud** of gases and cosmic dust that started to collapse due to the influence of its own gravity.

As the interstellar cloud collapsed, it started to rotate faster becoming increasingly hotter and forming a **primitive Sun** at its center.

The rotation caused the interstellar cloud to flatten out and take the form of a disk where dust grains in orbit around the star started to collide and merge, growing larger and forming **protoplanets**.

Planet formation

Formation of Earth

Earth formed a few million years after the Solar System, **~ 4 500 million years ago**.

The terrestrial materials were distributed according to their masses: the heavier ones moved to the center of the planet, while the lighter ones moved to its surface.

Earth was initially **very hot** and surrounded by a **primitive atmosphere**.

Formation of Earth

How do we know the age of Earth?

There are different **dating** methods that allow us to determine how long ago an event took place.

- ***Relative dating*** determines the relative order of past materials or events, without necessarily determining their absolute age. Examples: ***stratigraphy*** (based on the law of superposition of strata), ***dendrochronology*** (based on the study of growth rings of trees), ***biotic succession*** (based on the law of faunal succession of fossil species).
- ***Absolute dating*** determines a numerical age or range of past materials or events. Examples: ***thermoluminescence*** (for dating items to the last time they were heated), ***paleomagnetism*** (based on the study of the record of geomagnetic reversals of the Earth's magnetic field), ***radiometric dating*** (based on the presence of radioactive isotopes in materials).

Planet formation

Formation of Earth

How do we know the age of Earth?

Radiometric dating is based on the existence of unstable atomic nuclei of chemical elements that become, over time, different isotopes or more stable elements at a constant rate (***radioactive decay***). By comparing the abundance of *“parent”* and *“daughter”* isotopes within a material, it is possible to calculate how long ago that material was formed.

Example:

Carbon-14 is a radioactive isotope that takes 5 750 years to become nitrogen-14. Thus, if a material is composed of 50% carbon-14 and 50% nitrogen-14, the age of that material will be 5750 years.

Planet formation

History of Earth

In order to study the history of Earth, first we need to divide its 4 500 million years of age into units of time that include global processes and that can be divided into smaller units of time.

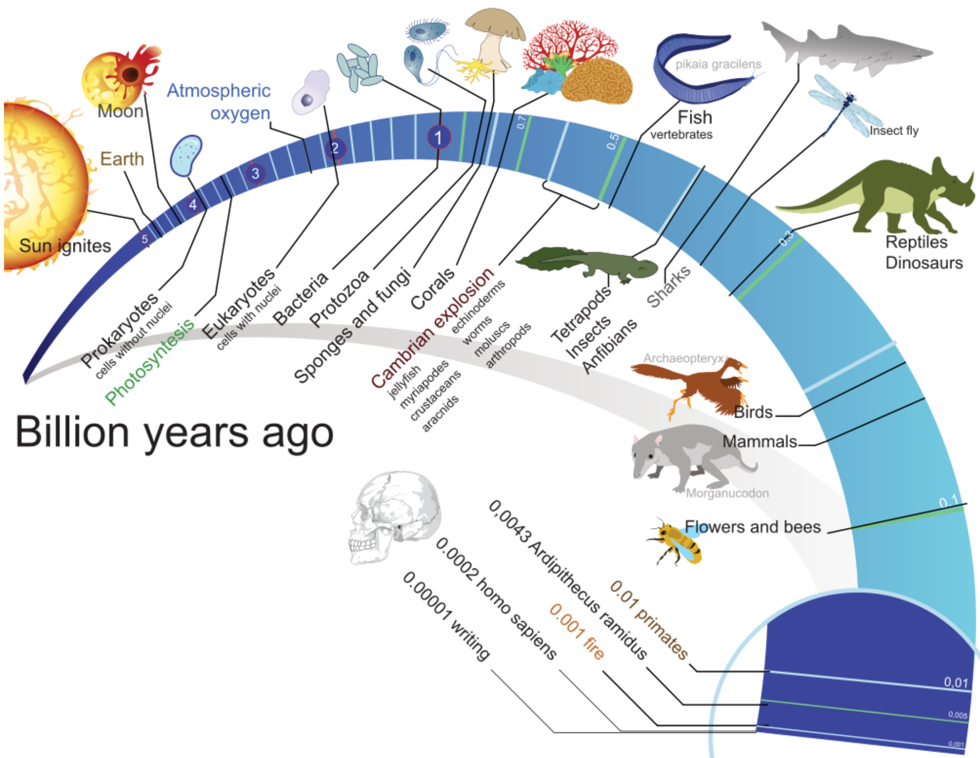


Image: LadyofHats
CC0

Planet formation

EON	ERA	PERIOD	Start (Ma)
Phanerozoic	Cenozoic	Quaternary	~2.6
		Neogene	~23
		Paleogene	~66
	Mesozoic	Cretaceous	~145
		Jurassic	~201
		Triassic	~252
	Paleozoic	Permian	~299
		Carboniferous	~359
		Devonian	~419
		Silurian	~444
		Ordovician	~485
		Cambrian	~541
Proterozoic			~2500
Archean			~4000
Hadean			~4500

Planet formation

<u>History of Earth</u>

The geological history of Earth is divided into two clearly differentiated parts:

1) **Precambrian.** It spans from the formation of Earth 4 500 Ma to 541 Ma. This period is the longest. The most important processes occurred during it, such as the ***formation of Earth***, the ***first life forms*** appeared, and the ***atmosphere*** was formed. This period includes three eons: the **Hadean**, the **Archean**, and the **Proterozoic**.

2) **Phanerozoic.** It spans from 541 Ma to the present. This is when Earth as we know it was formed, with the current continents and great variety of life forms. This period is divided into three eras: the **Paleozoic**, the **Mesozoic**, and the **Cenozoic**.

Planet formation

History of Earth: Precambrian

- **Hadean** (4 500 to 4 000 Ma): Formation of **Earth** and the **Moon**. Formation of the first **atmosphere** (without oxygen). Intense meteor bombardment. Formation of primitive **oceans**. Formation of first **rocks**.
- **Archean** (4 000 to 2 500 Ma): **Life** appears on Earth (unicellular anaerobic organisms without nucleus). Formation of first **continents**. Beginning of **plate tectonics**. **Oxygen** starts to be released to the atmosphere. Meteor bombardment stops.
- **Proterozoic** (2 500 to 541 Ma): The first continents assemble to form the supercontinent **Rodinia**. Oxygen accumulates in the Earth's atmosphere. First **glaciations** occur. Aerobic and **multi-cellular organisms** appear.

Planet formation

History of Earth: Phanerozoic

- **Paleozoic** (541 to 252 Ma) (***Cambrian***, ***Ordovician***, ***Silurian***, ***Devonian***, ***Carboniferous***, and ***Permian*** periods): The continents gather together into a supercontinent called **Pangaea**. The atmosphere reaches current oxygen levels. Invertebrates diversify. First **vertebrates** appear. Plants and animals come out of the water, colonizing Earth.
- **Mesozoic** (252 to 66 Ma) (***Triassic***, ***Jurassic***, and ***Cretaceous*** periods): **Dinosaurs** and other large reptiles appear, becoming the dominant terrestrial vertebrates on Earth. Pangea breaks apart. **Mammals** and **birds** appear.
- **Cenozoic** (66 Ma to the present day) (***Paleogene***, ***Neogene***, and ***Quaternary*** periods): Mammals diversify and become Earth's predominant fauna. The Atlantic Ocean widens. Earth's greatest mountain ranges form. **Hominids** appear.

Structure, composition and dynamics of Earth's layers

When Earth was formed, the heavier materials moved to the interior of the planet, while the lighter ones moved to its exterior.

Thus, Earth became layered in spherical shells, with a solid Earth (**geosphere**) divided into several layers and a gaseous Earth (**atmosphere**) around the solid Earth.

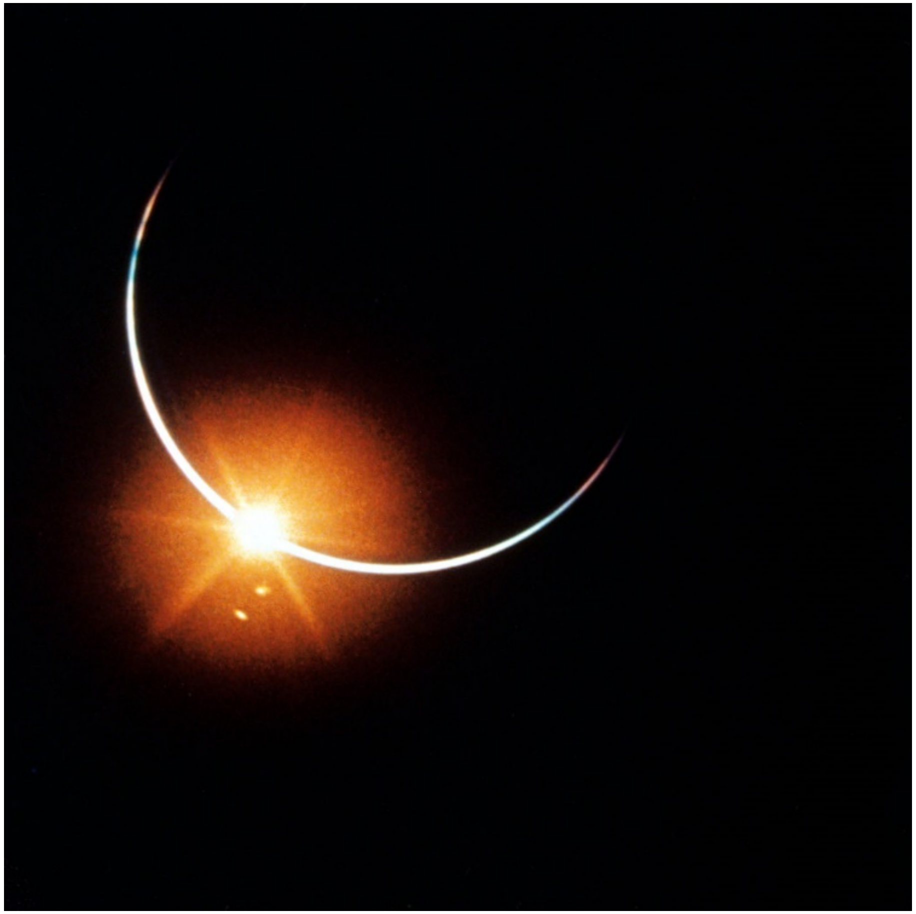
Besides, as Earth cooled, the water vapor in the primitive atmosphere condensed and accumulated over the Earth's surface in liquid form, originating the **hydrosphere**.

Image: NASA

Structure, composition and dynamics of Earth’s layers

Earth’s atmosphere

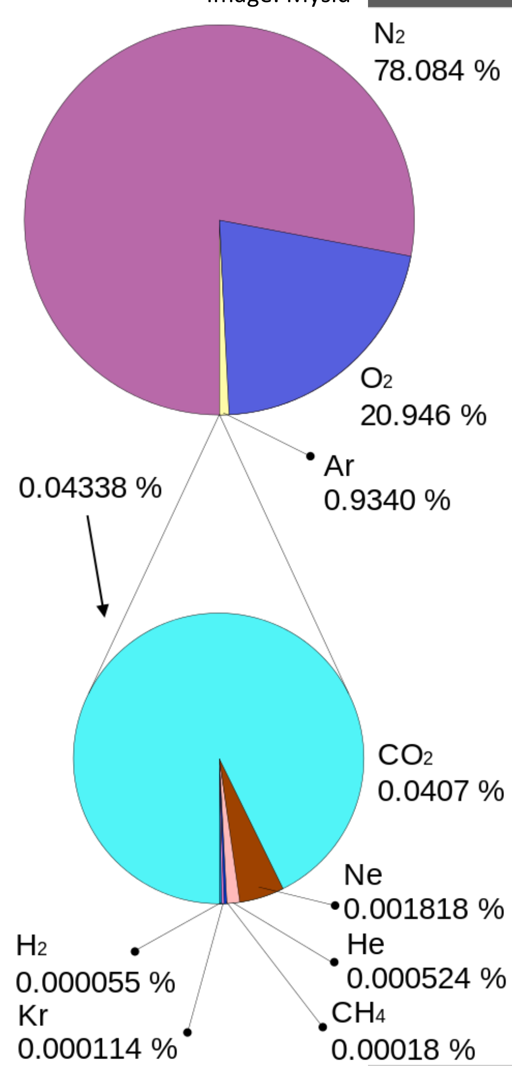
The **Earth’s atmosphere** is the **thin layer of gases** that surrounds the planet and is retained by Earth's gravity.



Earth's atmosphere backlit by the Sun in an eclipse observed from deep space onboard Apollo 12 in 1969.
Image: NASA

Earth's atmosphere: composition

The Earth's atmosphere is formed by a mixture of gases called **air**.



- ✓ Air is mainly composed by **nitrogen** (N_2), **oxygen** (O_2) and **argon** (Ar).
- ✓ The remaining gases are called **trace gases**: water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).
- ✓ Many **substances of natural origin** (dust, pollen, spores, sea spray, and volcanic ash) may be present in small amounts. **Industrial pollutants** may also be present.

Structure, composition and dynamics of Earth’s layers

Earth’s atmosphere: structure

The thickness of the Earth’s atmosphere is about **10 000 km**.

In the Earth's atmosphere, **temperature varies greatly with altitude**, which allows to divide it into layers.

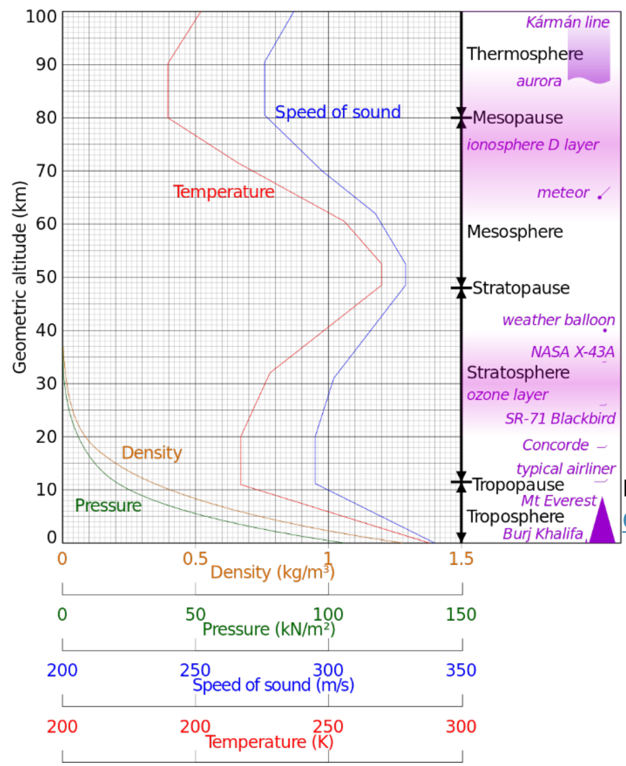


Image: Cmglee
CC BY-SA 3.0

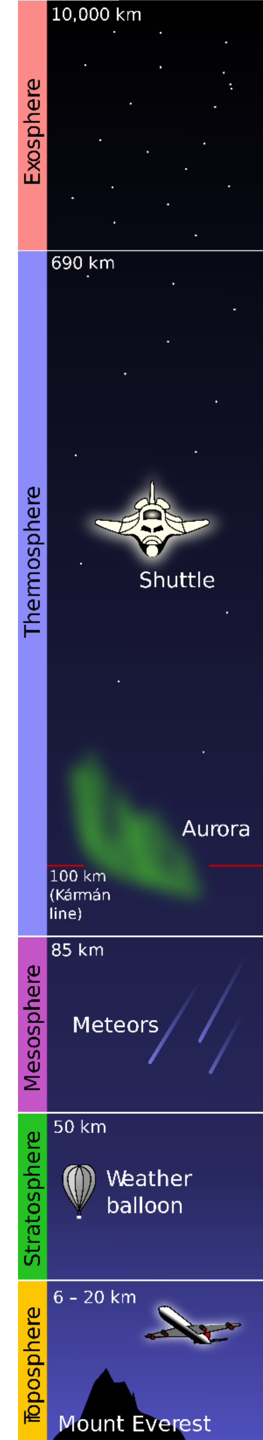


Image: NOAA

Structure, composition and dynamics of Earth’s layers

Earth’s atmosphere: structure - troposphere

The troposphere is the **lower layer** of Earth’s atmosphere, with a variable thickness (from 8 - 10 km at the polar regions to 14 - 16 km at the equator).

It contains approximately **80% of the mass of the Earth’s atmosphere** and nearly all its **water vapor**.

It is also where nearly all **weather phenomena** take place (winds, cloud formation, precipitation, etc.).

Temperature decreases as altitude increases, at a rate of approximately 1°C per 150 m.

The upper limit of the troposphere is the ***tropopause***.

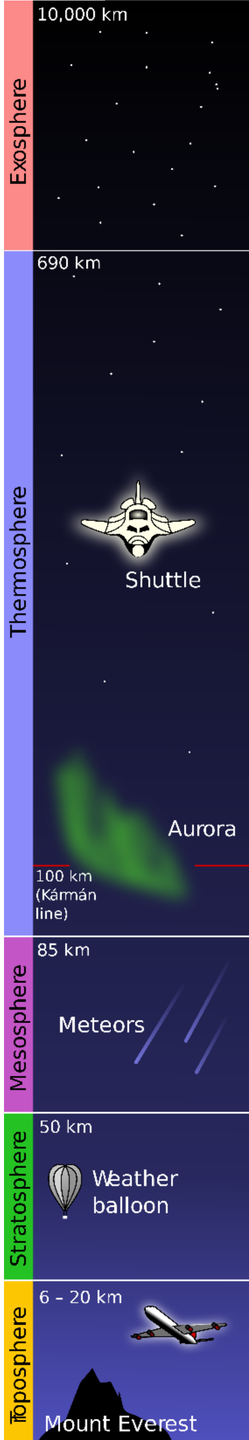


Image: NOAA

Structure, composition and dynamics of Earth's layers

<u>Earth's atmosphere: structure - stratosphere</u>

The stratosphere extends from the top of the troposphere to an altitude of about **50 km above the Earth's surface**.

It contains approximately **10% of the mass of the Earth's atmosphere**, and air is thinner here than in the troposphere.

It contains relatively high concentrations of ozone (***ozone layer***), which is formed by **UV solar radiation** acting over oxygen molecules.

Temperature increases with altitude due to the absorption of UV solar radiation by the ozone layer.

The upper limit of the stratosphere is called ***stratopause***.

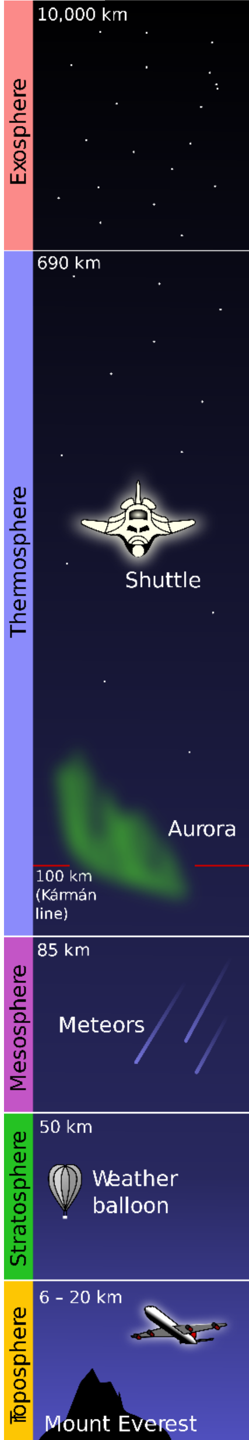


Image: NOAA

Structure, composition and dynamics of Earth's layers

<u>Earth's atmosphere: structure - mesosphere</u>

The mesosphere extends from the top of the stratosphere to an altitude of about **80 - 85 km above the Earth's surface**.

It contains only **0.1% of the mass of the Earth's atmosphere**.

Temperature decreases as altitude increases, reaching temperatures of about -100°C.

It is the layer where most **meteors** burn up when entering the atmosphere.

The upper limit of the mesosphere is called ***mesopause***, which is the coldest place on Earth.

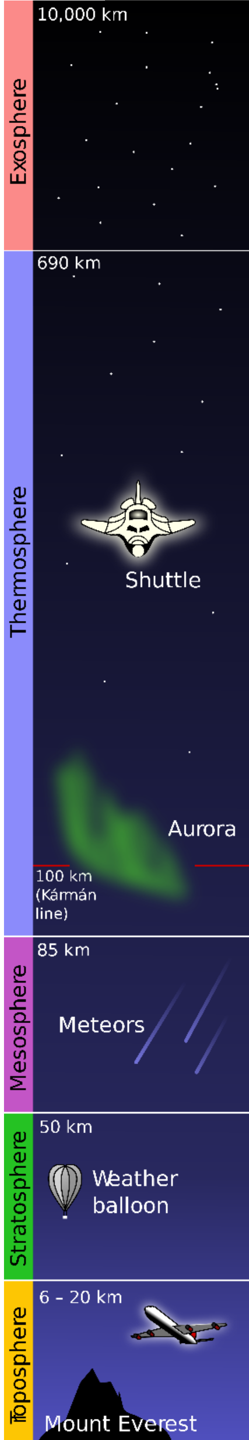


Image: NOAA

Structure, composition and dynamics of Earth’s layers

Earth’s atmosphere: structure - termosphere

The thermosphere extends from the top of the mesosphere to an altitude of about **350 - 800 km above the Earth’s surface** (depending on solar activity).

Within this layer, highly energetic solar radiation interacts with the residual atmospheric gases, creating **ions**. Due to the absorption of highly energetic solar radiation, the **temperature increases with altitude**.

The **aurora borealis** and **aurora australis** generally occur in this layer.

The upper limit of the termosphere is called ***thermopause***.

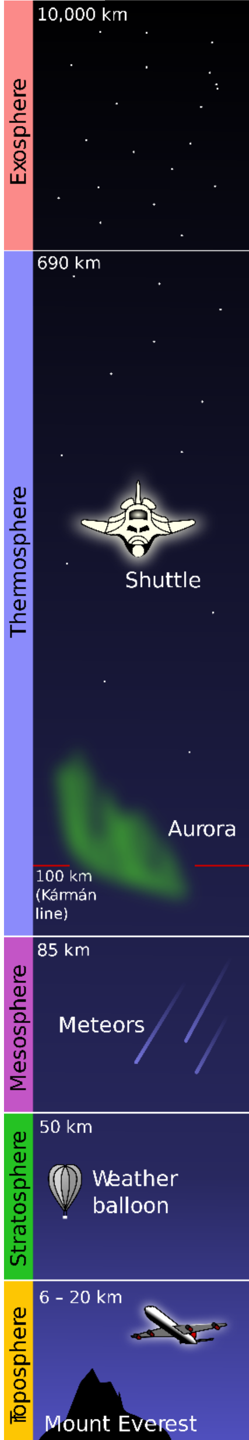


Image: NOAA

Structure, composition and dynamics of Earth’s layers

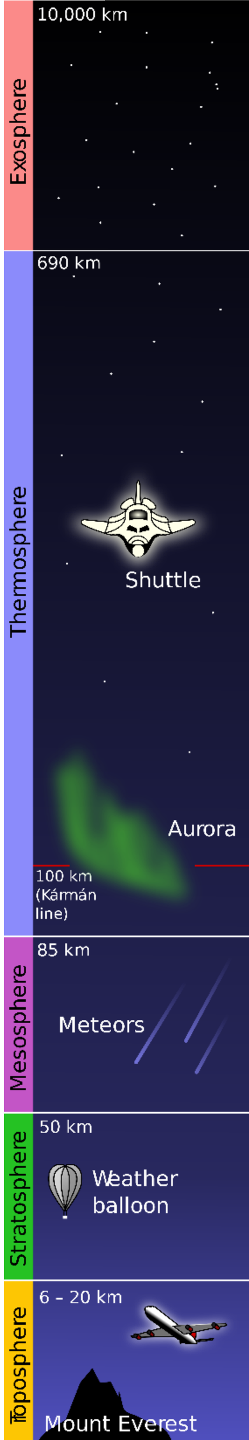


Image: NOAA

Earth’s atmosphere: structure - exosphere

The exosphere is the outermost layer of the Earth’s atmosphere, extending from the thermosphere to an altitude of about **10 000 km above the Earth’s surface**.

It is mainly composed of **hydrogen** and **helium**.

It is the **boundary between the Earth’s atmosphere and outer space**.

Earth's hydrosphere

The **Earth's hydrosphere** is the combined mass of **water** found on, under, and above the Earth's surface.

Approximately **75%** of the Earth's surface is covered by water.

Image: NASA

Structure, composition and dynamics of Earth's layers

<u>Earth's hydrosphere</u>

Water can be found on Earth in three different forms:

- ✓ **liquid**: oceans, seas, streams, lakes, groundwater.
- ✓ **solid**: polar ice caps, glaciers, snow.
- ✓ **gas**: water vapor, clouds.

Image: Jon Sullivan / pdphoto.org

Image: Luca Galuzzi - www.galuzzi.it
CC BY-SA 2.5

Image: PiccoloNamek at the English language Wikipedia
CC BY-SA 3.0

Earth's hydrosphere: properties of water

Pure water is a ***colorless***, ***odorless*** and ***tasteless*** liquid substance.

Image: fir0002 / flagstaffotos.com.au GFDL 1.2

Water molecules contain one **oxygen** and two **hydrogen** atoms (H_2O).

Earth's hydrosphere: properties of water

Water has important physical and chemical properties:

- ✓ It is **liquid** under standard conditions of temperature and pressure.
- ✓ Liquid water is the **universal solvent**. It contains substances (mineral salts, etc.) in solution in different concentrations. It is impossible to find pure water in nature. Many substances are dissolved in water (except fats and oils).
- ✓ It is a **poor conductor of heat**, which means that it takes a great amount of energy to increase its temperature. Water stores heat, regulates temperature variations and redistributes heat.
- ✓ **Solid water is less dense than liquid water**. Therefore, ice floats on liquid water, acting as a thermal insulator.
- ✓ Pure water does not conduct electricity. However, since it usually contains salt ions dissolved, it does conduct electricity.
- ✓ Water molecules attract each other, forming drops (**cohesion**). Water is also attracted to other substances and remains attached to them (**adhesion**).

Earth's hydrosphere: distribution of water on Earth

97% of the Earth's water is found in the **oceans** and **seas**, with only **3%** being **fresh water**.

Of the fresh water, most of it is frozen in the **polar ice caps** and **glaciers** (**69%**), while **30%** of the rest is **groundwater** and **1%** is surface water in **lakes**, **swamps** and **rivers**.

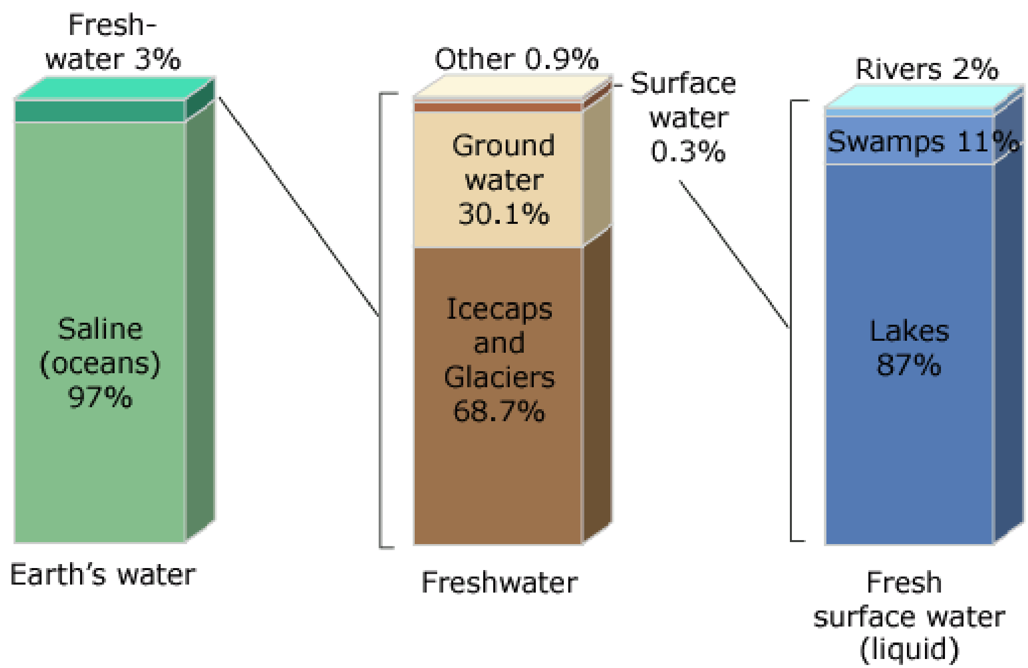


Image: USGS

Earth's hydrosphere: the water cycle

The mass of water on Earth is in continuous movement from one reservoir to another (oceans, glaciers, etc.). This dynamic process is called **water cycle**.

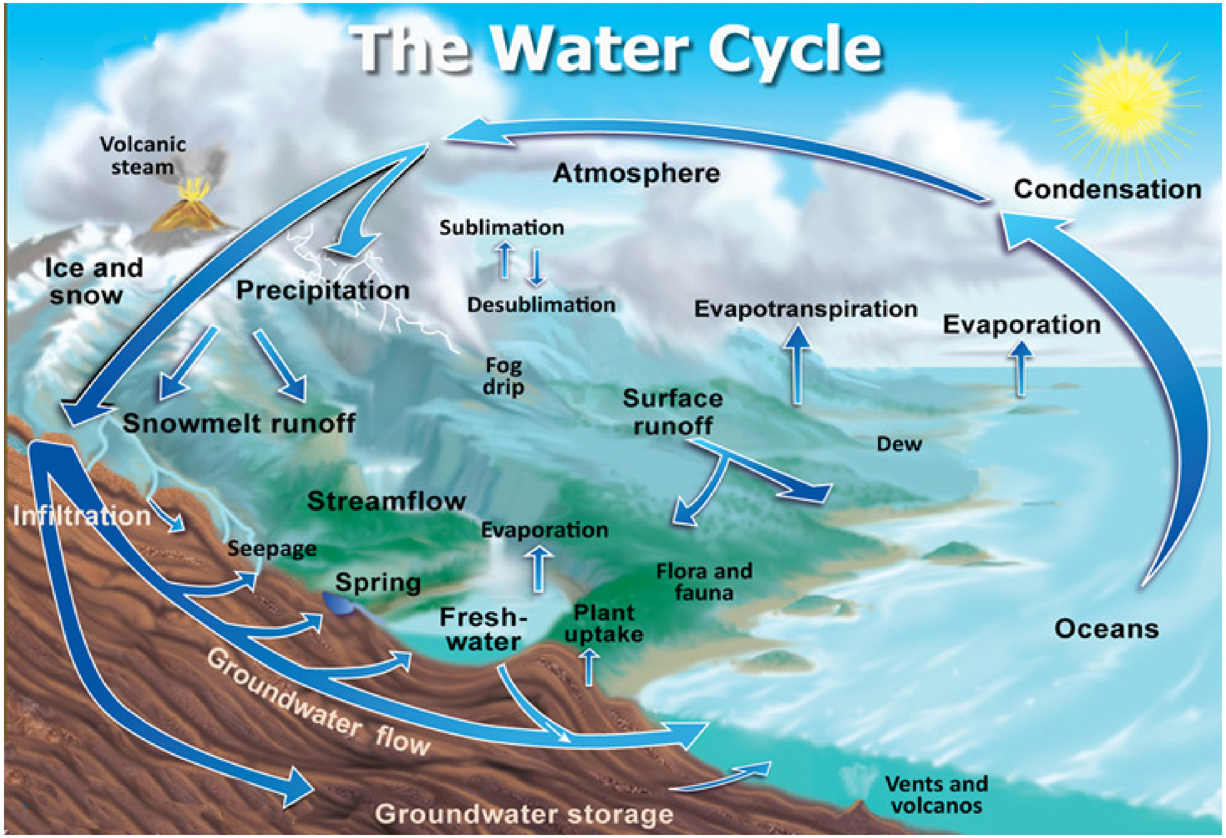


Image: USGS

Earth's hydrosphere: the water cycle

The main processes of the water cycle are:

1. **Evaporation.** Water from oceans, lakes, streams, and other sources such as the soil and the plants (***evapotranspiration***), evaporates due to the Sun's energy.
2. **Condensation.** Water vapor rises and condenses as ***clouds***, which are made of tiny droplets.
3. **Precipitation.** Water droplets fall from clouds to the Earth's surface. Most precipitation occurs as liquid water (***rain***), but it can also occur as frozen water (***snow*** or ***hail***).
4. **Runoff.** Water flows above ground, forming ***streams***, ***rivers***, ***swamps***, ***ponds***, and ***lakes***.
5. **Infiltration.** Water flows from the ground surface into the ground. Once infiltrated, the water becomes ***soil moisture*** or ***groundwater***.

Earth's hydrosphere: the importance of water

Water is essential to living organisms and the sustainability of the planet:

1. **Living organisms:** All organisms need water to live. Approximately 60% of the human body is water. Life started in the primitive oceans about 3 600 million years ago. Water is essential for many life processes: it allows maintaining a stable temperature, transports nutrients and other substances, intervenes in many fundamental metabolic reactions (respiration, photosynthesis, etc.), etc.
2. **Climate:** Clouds distribute water through the planet. More locally, water heats and cools more slowly than land. Therefore, coastal zones have a more moderate climate than continental zones, since the temperature range between day and night is much smaller.
3. **Landscape:** Water erodes, transports and deposites solid particles (sediment) as it flows. This has an impact on the processes shaping the landscape.

Structure, composition and dynamics of Earth's layers

<u>Earth's geosphere</u>

The **Earth's geosphere** is the **mineral** part of the Earth.

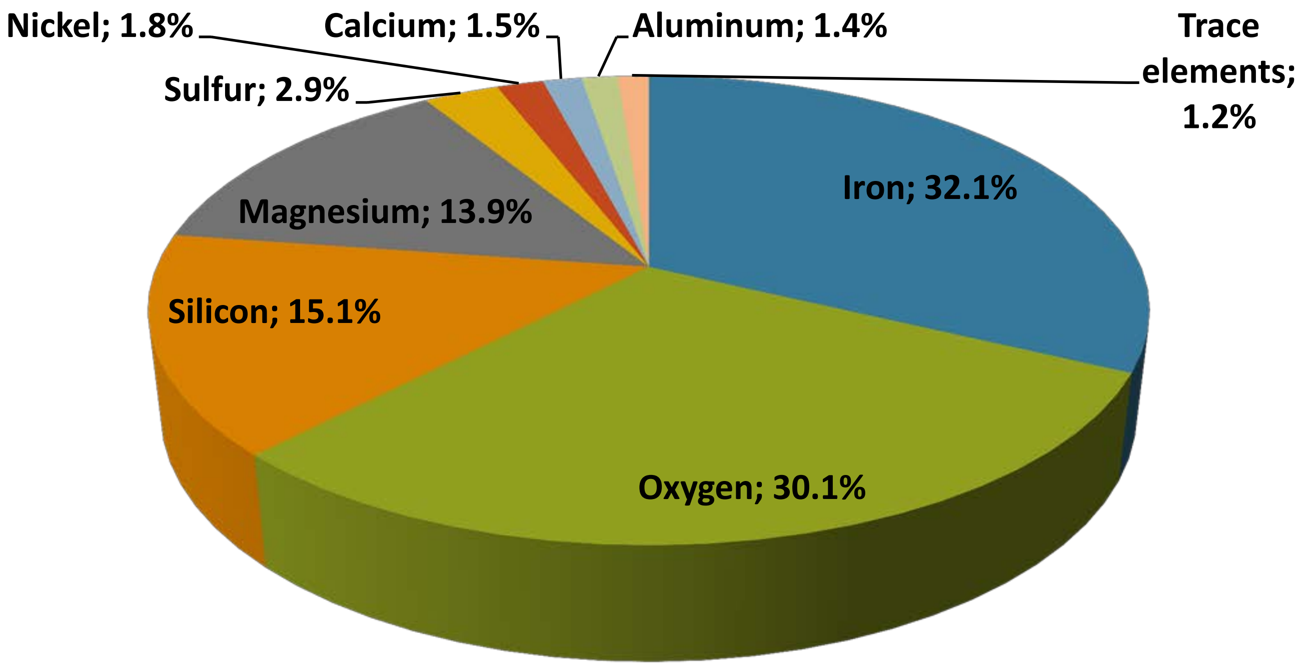
Image: shrimpo1967
CC BY-SA 2.0

Image: Jim D. Griggs (USGS)

The rocky material from the Earth's geosphere can be found in ***solid*** or ***fluid*** forms.

Earth's geosphere: composition

Earth is composed mostly of **iron**, **oxygen**, **silicon**, magnesium, sulfur, nickel, calcium, aluminum, and trace amounts of other elements.



Structure, composition and dynamics of Earth's layers

Earth's geosphere: structure

Earth's interior is divided in spherical shells with increasing density:

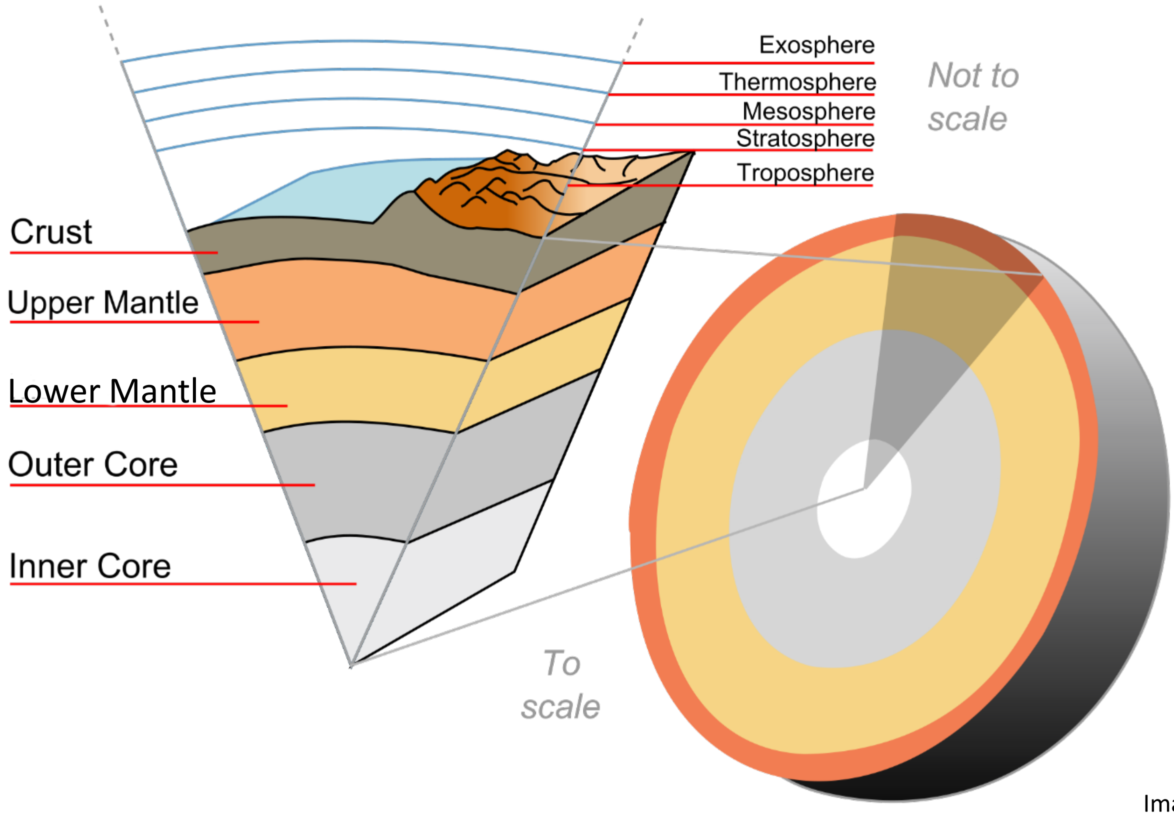


Image: Surachit
[CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0)

Structure, composition and dynamics of Earth's layers

Earth's geosphere: structure - crust

It is the **outermost layer** of the Earth's geosphere, with an average thickness of ***30 km*** (6 - 70 km). It is composed of **solid rocks** which form the ***tectonic plates*** and the ***soil***.

The most abundant chemical elements of the Earth's crust are ***oxygen*** and ***silicon***.

- ✓ **Continental crust.** It forms the continents and the areas of shallow seabed of the oceans. It is composed of less dense rocks, such as ***granite***.
- ✓ **Oceanic crust.** It underlies the ocean basins. It is composed of denser rocks, such as ***basalt***.

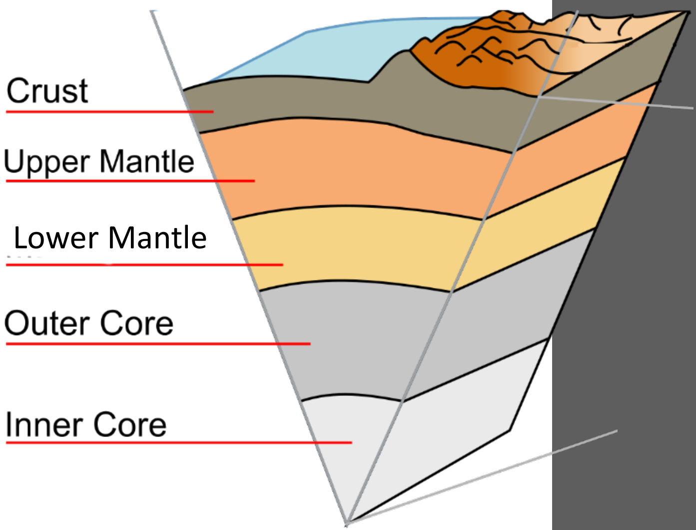


Image: Surachit / A.R. Esteve
CC BY-SA 3.0

Structure, composition and dynamics of Earth's layers

Earth's geosphere: structure - mantle

It is the **layer inside** the Earth's geosphere. It is the thickest layer, extending to a ***depth of 2 900 km***.

The most abundant chemical elements of the Earth's mantle are ***iron*** and ***magnesium***.

- ✓ **Upper mantle** (35 - 700 km). It is composed of rocks in ***fluid*** form.
- ✓ **Lower mantle** (700 - 2 900 km). It is composed of ***solid*** rocks.

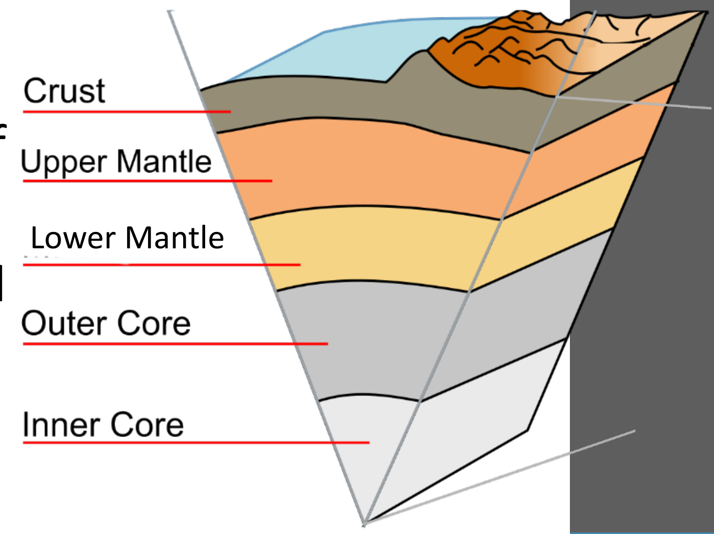


Image: Surachit / A.R. Esteve
CC BY-SA 3.0

Structure, composition and dynamics of Earth's layers

<u>Earth's geosphere: structure - core</u>

It is the **innermost layer** of the Earth's geosphere, ***extending from a depth of 2 900 km to 6 371 km***. It represents 60% of the total mass of the Earth.

The most abundant chemical elements of the Earth's core are metals, mostly ***iron*** and ***nickel***.

- ✓ **Outer core** (2 900 - 5 100 km). It is composed of rocks in ***liquid*** form. It is believed that ***the Earth's magnetic field*** is caused by the motion of these molten materials.
- ✓ **Inner core** (5 100 - 6 371). It is composed of ***solid*** rocks.

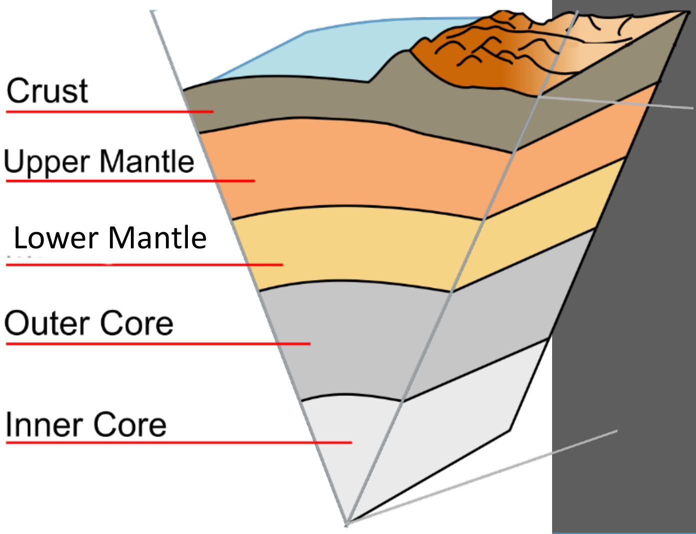


Image: Surachit / A.R. Esteve
CC BY-SA 3.0

Earth's geosphere: structure

How are the Earth's composition and structure known?

1. **Earth's density**

$$\boxed{average\ Earth's\ density = 5.5\ g/cm^3}$$

$$Universal\ Gravitation\ law \rightarrow g = G\frac{M_T}{{R_T}^2}$$

$$density \rightarrow d = \frac{M_T}{V_T}$$

$$\boxed{density\ of\ Earth's\ surface\ (granite) = 2.2\ g/cm^3}$$

Therefore, there must be denser materials inside of Earth than on the Earth's surface.

Structure, composition and dynamics of Earth's layers

<u>Earth's geosphere: structure</u>

How are the Earth's composition and structure known?

2. Meteorites

Since Earth was formed by accretion of **meteorites**, they provide information about the substances that compose planets.

Image: H. Raab
CC BY-SA 3.0

Image: Dr. Svend Buhl
Niger Meteorite Recon
CC BY 3.0

Image: Dr. Svend Buhl
Niger Meteorite Recon
CC BY 3.0

For example, 86% of the meteorites that fall on Earth are **chondrites**, which are composed of ***peridotite*** like the ***Earth's mantle***. Other types of meteorites are **acondrites** (8%), which are composed of ***basalt*** as the ***oceanic crust***, and **metal meteorites** (5%), which are composed of ***iron*** and ***nickel*** like the ***Earth's core***.

Structure, composition and dynamics of Earth's layers

<u>Earth's geosphere: structure</u>

How are the Earth's composition and structure known?

3. Seismic waves

When the ***propagation speed*** of a seismic wave experiences a very distinct change, this is due to a change in the ***properties of the medium*** (density, viscosity, etc.) through which the seismic wave travels. This allows the internal structure of Earth to be inferred.

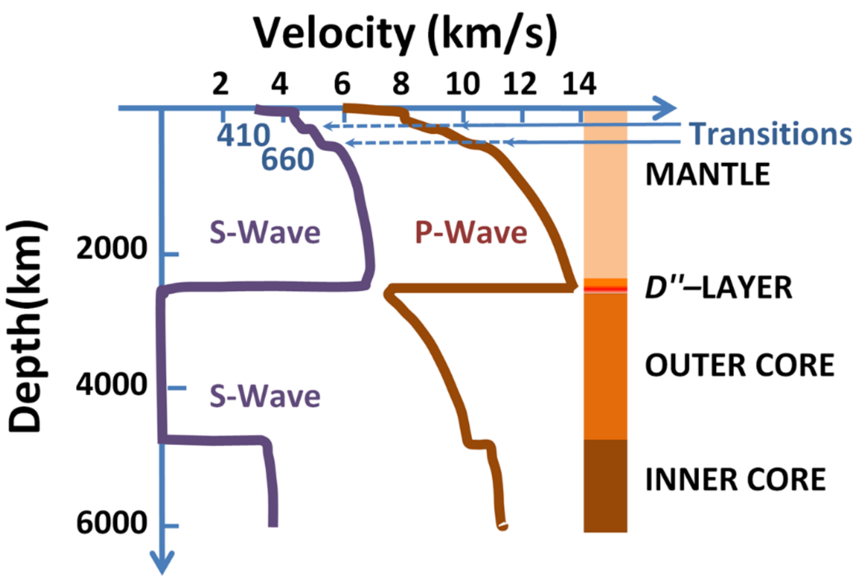


Image: Brews ohare
CC BY-SA 3.0

Structure, composition and dynamics of Earth's layers

Earth's geosphere: minerals and rocks

Different materials, usually in solid form, can be found on the Earth's surface. These materials, which have different origins and compositions, form what is generally called ***stones***, ***soil***, ***sand***, etc.

Image: Dirk van der Made
CC BY-SA 3.0

Image: Didier Descouens
CC BY-SA 3.0

These materials are called ***minerals*** and ***rocks*** in Geology.

Structure, composition and dynamics of Earth's layers

Earth's geosphere: minerals and rocks

A **mineral** is a ***naturally occurring inorganic solid substance*** with a ***specific chemical composition*** and an ***ordered internal structure***.

Quartz (SiO_2)
Image: Didier Descouens
CC BY-SA 4.0

Pyrite (FeS_2)
Image: Fir0002 at English Wikipedia
CC BY-SA 3.0

Diamond
Image: Steve Jurvetson
CC BY 2.0

Its formation only depends on the ***chemical elements*** which were present while the mineral was formed and the ***physical properties*** (pressure and temperature) under which the mineral was formed.

Structure, composition and dynamics of Earth's layers

Earth's geosphere: minerals and rocks

A **rock** is a natural substance composed of one or more minerals and formed and transformed through ***geological processes*** (a volcano, the deposition of sediments by a river, etc.)

Granite (Igneous rock)
Image: Der Messer
CC BY 3.0

Sedimentary rocks
Image: PePeEfe
GFDL

Marble (Metamorphic rock)
Image: Aleksander Kaasik
CC BY-SA 4.0

Plate tectonics

Plate tectonics is a scientific theory which describes the ***geological processes*** occurring on ***Earth***: earthquakes, volcanoes, mountain-building, etc.

Image: G.E. Ulrich (USGS)

Image: Tobias Helfrich
CC BY-SA 3.0

Image: Pavel Novak
CC BY-SA 2.5

This theory was developed by ***geologists***, ***geophysicists,*** and ***seismologists*** who collaborated providing information about the structure of the continents, the ocean basins and Earth's interior.

Plate tectonics

Background

Plate tectonics is based on two previous theories:

1. **Continental drift.**

2. **Seafloor spreading.**

Plate tectonics

Background: continental drift

Continental drift is a theory proposed by **Alfred Wegener** (1880–1930) in **1912**.

This theory states that the continents had once formed a single supercontinent called **Pangaea**, about 300 million years ago.

Pangaea broke apart and its fragments drifted to their present locations.

Image: Kieff
CC BY-SA 3.0

Plate tectonics

Background: continental drift

Evidence of the **continental drift** includes:

1. **Geographical evidence:** the shapes of continents on opposite sides of the oceans seem to fit together (*e.g., Africa and South America*).
2. **Geological evidence:** similar minerals and rocks have been found on separate continents (*e.g., diamonds in Brazil and South Africa*).
3. **Paleoclimatic evidence:** sediments that indicate similar climates have been found on separate continents (*e.g., glacial sediments from the same time period in Antarctica and Australia*).
4. **Fossil evidence:** similar plant and animal fossils have been found on separate continents (*e.g., Mesosaurus in Africa and South America*).

Despite these evidences, this theory was rejected by some geologists since ***it could not explain the mechanism responsible for the continental drift***.

Background: mantle convection

Arthur Holmes (1890–1965) proposed in **1944** that the Earth's mantle contained ***convection cells*** that transported heat from the Earth's interior to the surface.

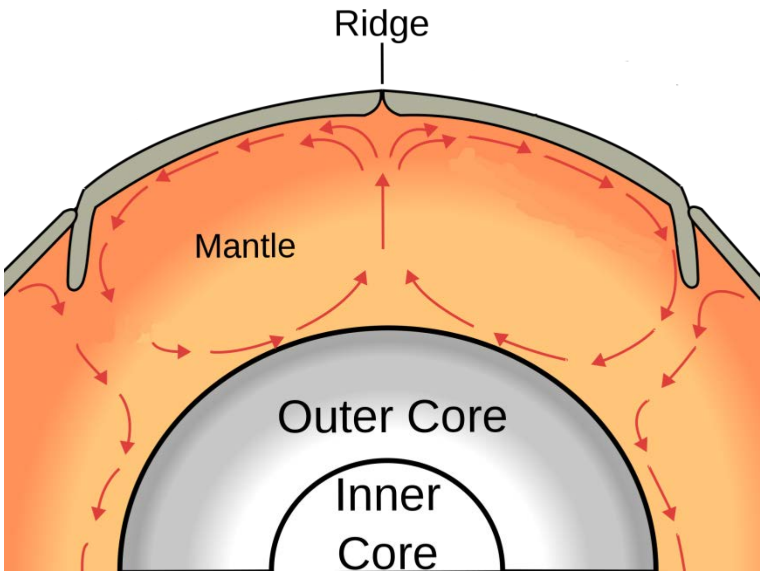


Image: Surachit / A.R. Esteve
CC BY-SA 3.0

These convection cells in the Earth's mantle are responsible for the ***continental drift***.

Plate tectonics

<u>Background: mantle convection</u>

The heat from the interior of the Earth which is carried to the surface by the mantle's convection cells is responsible for the motion of the tectonic plates around the Earth's surface.

The heat from the interior of the Earth comes from two main sources:

1. The ***Earth's core*** looses ***heat*** left over from the ***formation of Earth***. The composition of Earth's core allows it to release this heat gradually.
2. The ***radioactive decay of elements*** in the Earth's mantle and crust (U-235, U-238, Th-232 and K-40) produces heat which is released gradually.

Plate tectonics

Background: seafloor spreading

Seafloor spreading is a theory proposed by **Harry Hess** (1906–1969) in the 1960s.

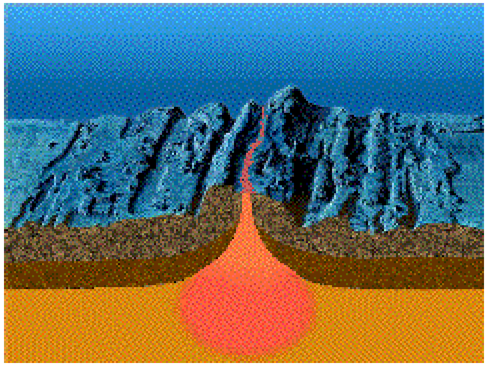


Image: USGS

This theory states that the seafloor expands with the material from the Earth's mantle that rises through ***mid-ocean ridges****. This process, besides spreading the seafloor, moves the Earth's tectonic plates and pulls apart continents.

****Mid-ocean ridges*** are large underwater mountain systems which have a central valley (***rift***). Magma from the Earth's interior emerges constantly through them forming new crust upon cooling along their sides.

Plate tectonics

<u>Background: seafloor spreading</u>

Evidence of the **seafloor spreading** includes:

1. ***Seafloor magnetic striping*.**
2. ***Age of the rocks on the seafloor*.**
3. ***Thickness of the sediment layer on the seafloor.***

Plate tectonics

Background: seafloor spreading

Seafloor spreading forms new oceanic crust that spreads away from the mid-ocean ridges. When magma from the Earth's interior emerges and cools, the ***Earth's magnetic field*** at the time is recorded.

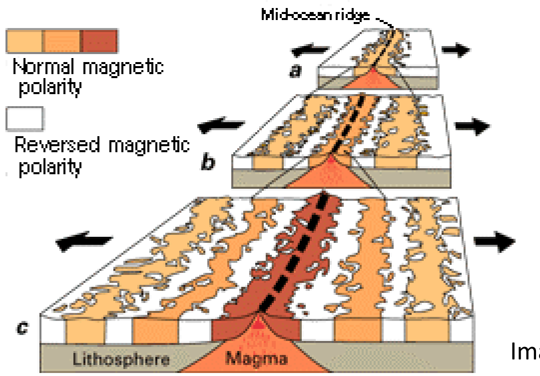


Image: USGS

Earth's magnetic field switches the position of its poles from time to time, and a symmetrical pattern of magnetic stripes is observed from the center of the mid-ocean ridge across the seafloor (***magnetic striping***) .

Plate tectonics

Background: seafloor spreading

The rocks closer to the mid-ocean ridges are the youngest rocks on the seafloor, and the ***age of the rocks on the seafloor*** increases equally and symmetrically on both sides of the mid-ocean ridge.

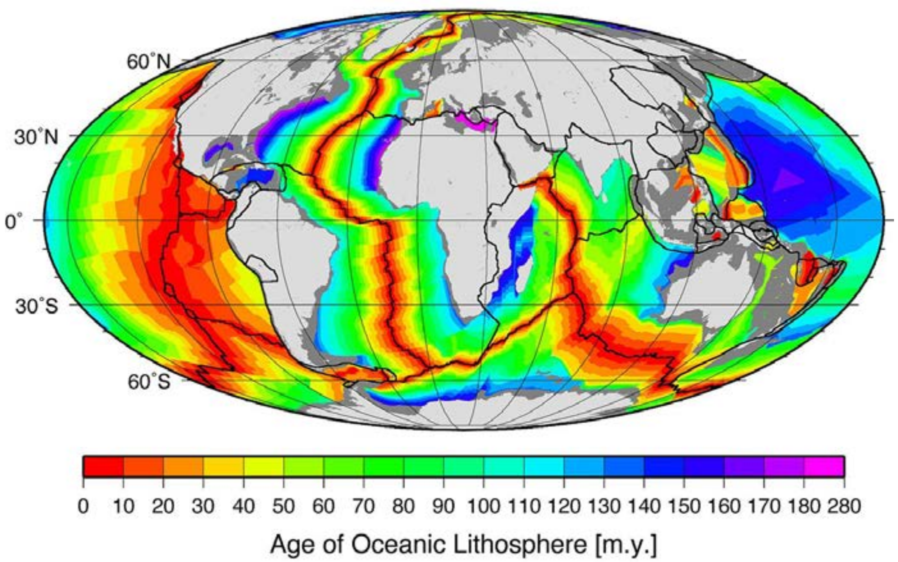


Image: NOAA

Moreover, the ***thickness of the sediment layer on the seafloor*** increases in both directions away from the mid-ocean ridge. The seafloor is thinner at the mid-ocean ridge and grows thicker as the crust becomes older.

Background: seafloor spreading

How is it possible that oceanic crust is continuously formed at the mid-ocean ridges without the size of the Earth's surface being increased?

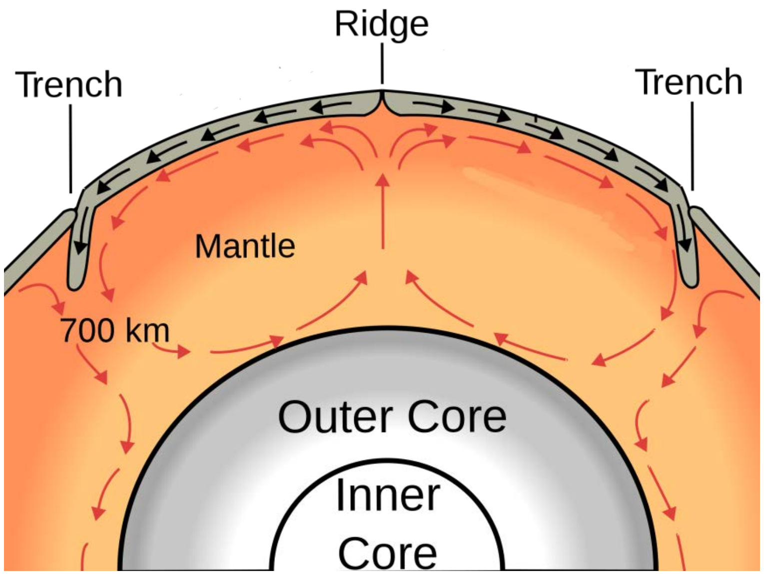


Image: Surachit / A.R. Esteve
CC BY-SA 3.0

Oceanic crust is formed at the ***mid-ocean ridges***, and it is destroyed, many millions of yeas later, at ***oceanic trenches***. Thus, the size of the Earth's surface does not increase with seafloor spreading.

Plate tectonics

Plate tectonics

Plate tectonics (1968) is a theory which states that the Earth's surface is divided in ***tectonic plates*** which are able to move over the Earth's upper mantle.

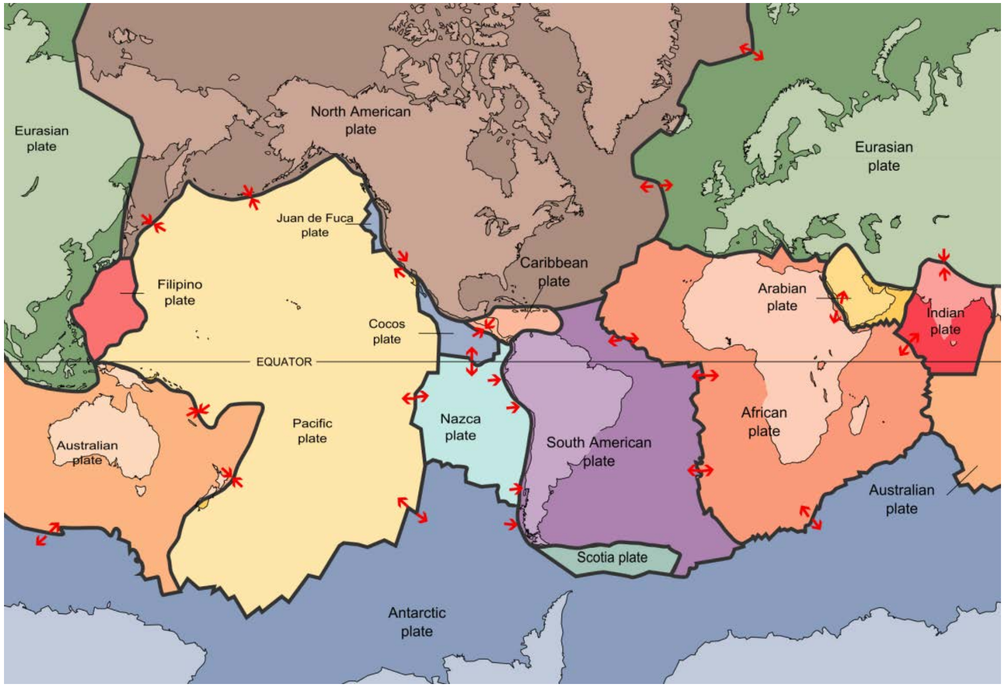


Image: USGS

The tectonic plates are rigid and consist of pieces of Earth's crust (oceanic and continental) and the upper mantle.

Plate tectonics

Plate tectonics

Plate tectonics basically proposes the following:

- ✓ The **heat transport** through the Earth's mantle is carried out by **convection cells**.
- ✓ The **Earth's surface** is divided in **tectonic plates** which correspond to the surface current of each convection cell.
- ✓ Where two contiguous **convective cells** are **ascending**, a **mid-ocean ridge** forms and **oceanic crust is created**.
- ✓ Where two contiguous **convective cells** are **descending**, an **oceanic trench** forms and **oceanic crust is destroyed**.
- ✓ The low density of the continental crust doesn't allow it to sink to the mantle.
- ✓ The **plate boundaries** are **the most unstable areas**.

<u>Plate tectonics</u>

Plate tectonics explains many geological phenomena:

- ✓ ***Tectonic plates*** which form the Earth's surface and their motion.
- ✓ The ***formation of mountain ranges***.
- ✓ ***Seafloor spreading***.
- ✓ The ***distribution of earthquakes and volcanoes*** in specific regions of Earth.
- ✓ The ***past and current location of continents and oceans***.
- ✓ The ***distribution of mineral deposits and fossil fuels***.

Plate tectonics

Tectonic plate interactions

Tectonic plates move very slowly (~2.5 cm/yr), and this provokes continuous changes in their size and shape.

According to the type of boundary between tectonic plates, three types of **tectonic plate interactions** exist:

1. **Divergent boundaries** (***constructive***).
2. **Convergent boundaries** (***destructive***).
3. **Transform boundaries** (***conservative***).

Plate tectonics

Tectonic plate interactions

At **divergent boundaries**, two tectonic plates move away from each other and the space that this creates is filled with new material sourced from molten magma that forms below. They are also known as ***constructive boundaries***.

They form ***mid-ocean ridges***.

Examples: Africa's Great Rift Valley, the Red Sea, the Atlantic Ocean.

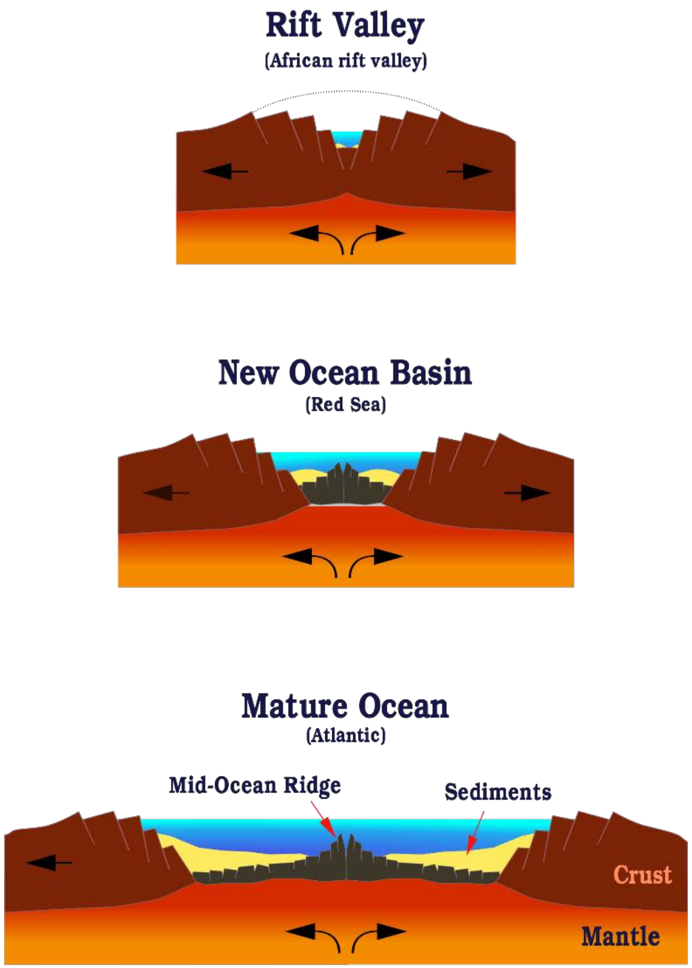


Image: Hannes Grobe/Lichtspiel
CC BY-SA 2.5

Plate tectonics

<u>Tectonic plate interactions</u>

At **convergent boundaries**, two tectonic plates move toward each other and one plate (the densest) moves under another (less dense) sinking into the mantle (***subduction***). They are also known as ***destructive boundaries***.

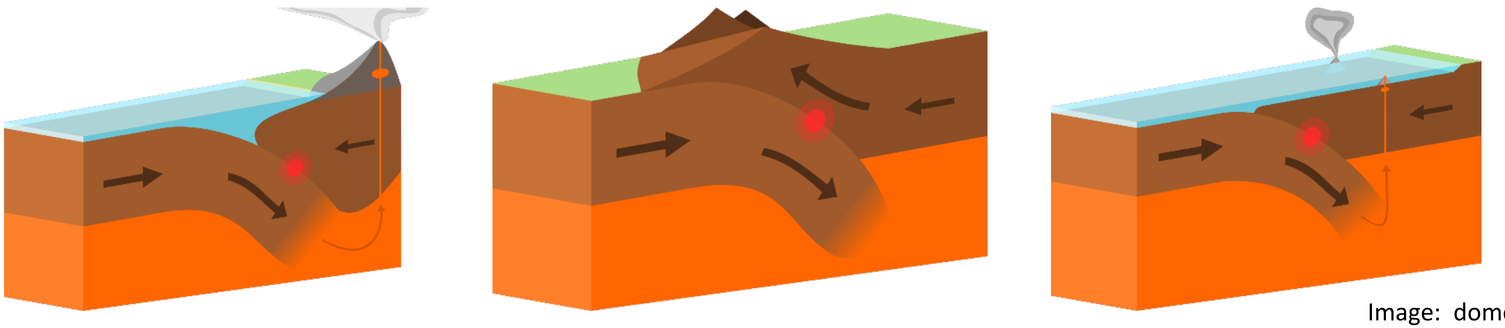


Image: domdomegg
CC BY 4.0

They form ***oceanic trenches***.

Examples: the Andes (ocean-to-continent boundary), the Himalayas (continent-to-continent boundary), Japanese island arc (ocean-to-ocean boundary).

Plate tectonics

<u>Tectonic plate interactions</u>

At **transform boundaries** (or ***transform fault***), two tectonic plates grind into each other and their motion is predominantly horizontal. They are also known as ***conservative boundaries*** since plates are neither created nor destroyed.

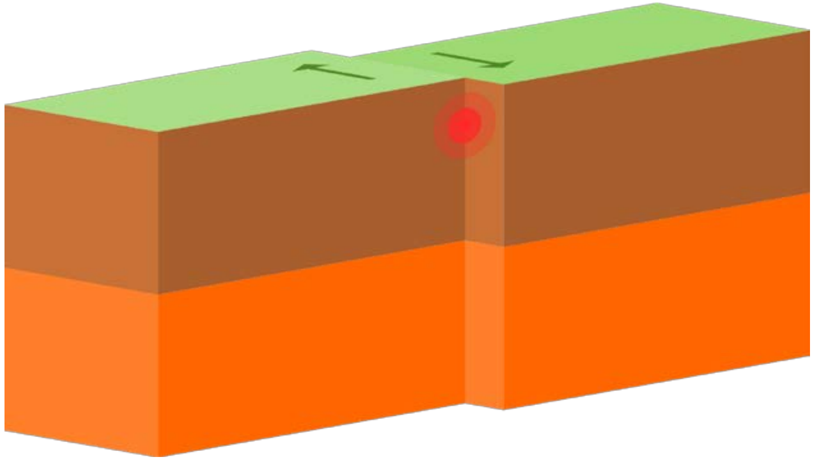


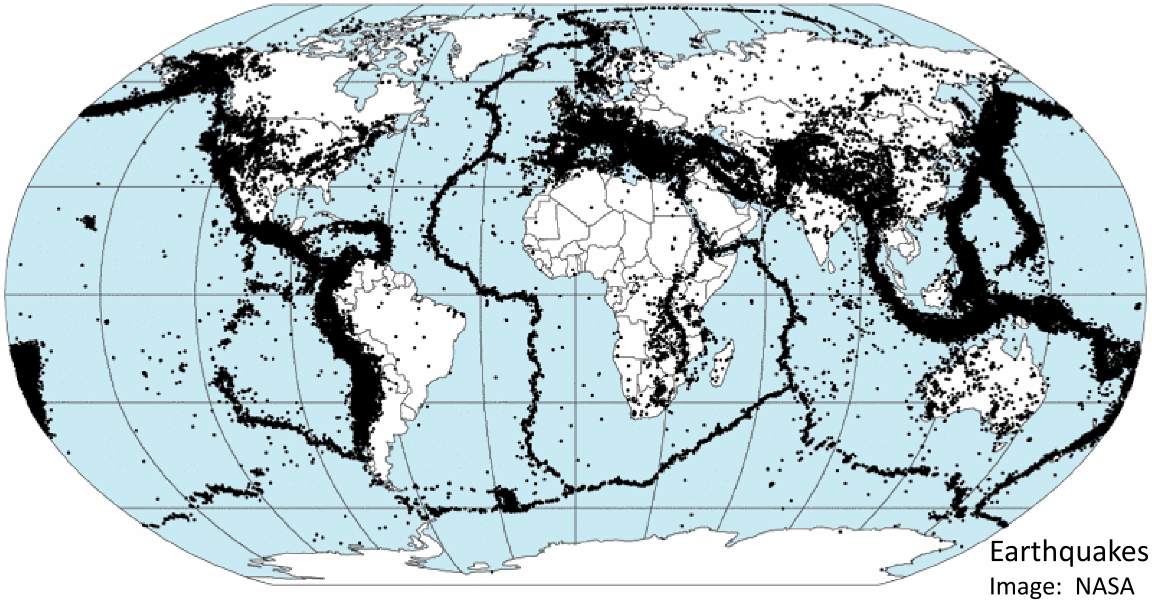
Image: domdomegg
CC BY 4.0

Transform boundaries relieve the strain (energy) accumulated between the edges of the tectonic plates in the form of seismic waves causing **earthquakes**.

Plate tectonics

Tectonic plate interactions

Most **earthquakes** and **volcanic eruptions** occur in the boundaries between tectonic plates.



Earthquakes between 1963 and 1998.
Image: NASA

The two most active regions in the world are:

- the **Ring of Fire** in the basin of the Pacific Ocean.
- the **Alpide belt** in the mountain ranges along the southern margin of Eurasia.

Tectonic plate interactions: volcanoes

A **volcano** is a rupture in the Earth's crust which allows ***magma*** to escape from below the surface.

Image: G.E. Ulrich (USGS)

Magma is expelled from a volcano during ***volcanic eruptions***, which vary widely in strength, intensity, duration and frequency.

Plate tectonics

Tectonic plate interactions: volcanoes

The main features of a volcano are:

- **Magma chamber:** large pool of molten rock (magma) beneath the Earth's surface.
- **Volcanic vent:** conduct through which magma erupts.
- **Volcanic cone:** built by the materials that come out of the volcanic vent, piling up around the vent in the shape of a cone.
- **Crater:** roughly circular depression from which the magma is erupted as lava.

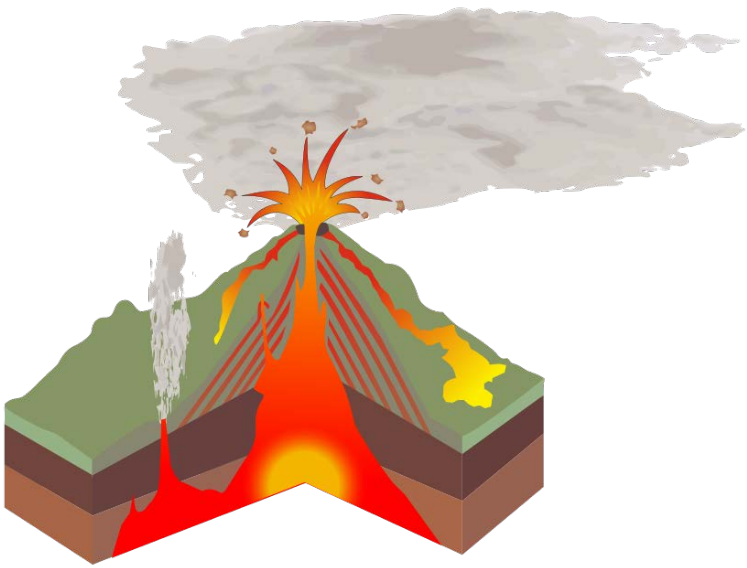


Image: William Crochot
CC BY-SA 4.0

Plate tectonics

Tectonic plate interactions: volcanoes

The erupted materials from a volcano are:

- Solid. **Tephra** is violently expelled in volcanic eruptions due to the pressure that has built inside the volcano. These materials are classified by size: ***ash*** (< 2 mm), ***lapilli*** (2 - 64 mm), and ***volcanic bombs*** (> 64 mm).

- Molten. The erupted magma (***lava***) flows piling up around the volcanic vent in the shape of a cone.

- Gas. Gases released by a volcano are usually ***water vapor*** and ***sulfur compounds***.

Image: Árni Friðriksson
CC BY-SA 3.0

Image: Hawaii Volcano Observatory (DAS)

Plate tectonics

Tectonic plate interactions: earthquakes

An **earthquake** is the sudden shaking of the Earth's surface which can range in intensity and frequency.

Image: Logan Abassi (United Nations Development Programme) CC BY 2.0

An earthquake's effects depend on several factors (the earthquake's magnitude, the location of the epicenter, the distance from the epicenter, the population density...), and can vary widely.

Plate tectonics

<u>Tectonic plate interactions: earthquakes</u>

The slow motion of the tectonic plates accumulates strain (energy) until it is suddenly released in the form of ***seismic waves*** causing earthquakes.

The **hypocenter** is the point inside the Earth where the earthquake originates.

The **epicenter**, located directly above the hypocenter, is the point on the Earth's surface where the greatest damage takes place.

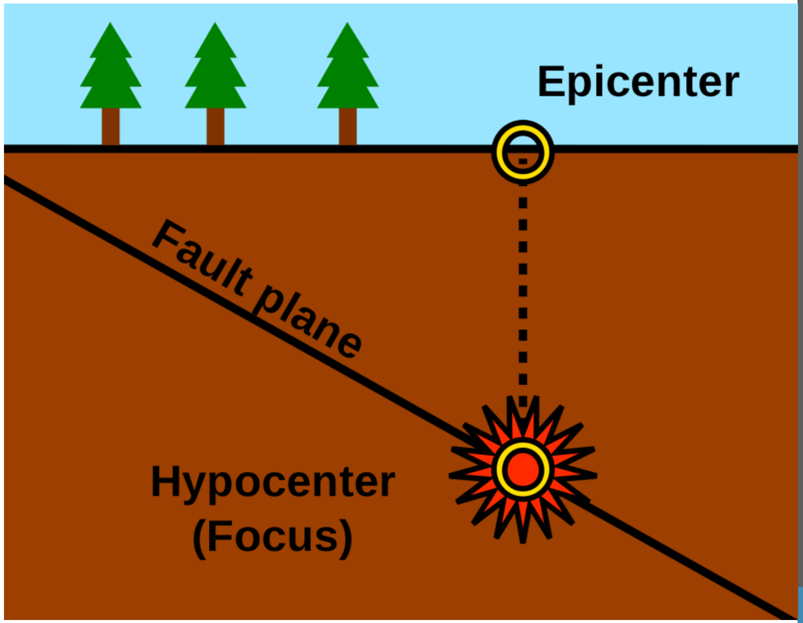


Image: Sam Hocevar/Ansate
CC BY-SA 1.0

Plate tectonics

Tectonic plate interactions: earthquakes

If an earthquake's epicenter is below the ocean, it may cause a ***tsunami***, which consists of large waves with high destructive power.

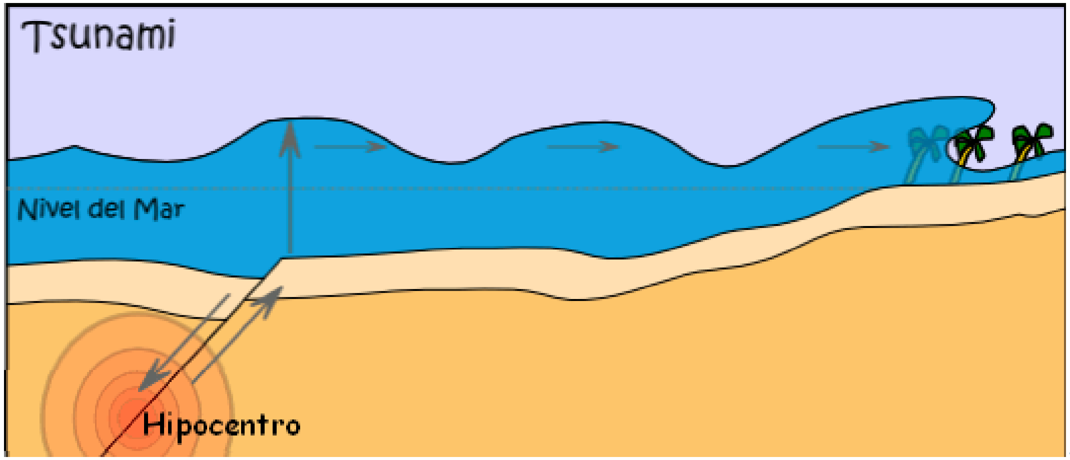


Image: Yearofthedragon at Spanish Wikipedia [CC BY-SA 3.0]

Example: On March 2011, a powerful earthquake with the epicenter located 130 km off the coast of Japan and at an underwater depth of 32 km caused tsunami waves that reached heights of up to 40 m that brought destruction along the coast and damaged the Fukushima Nuclear Power Plant, provoking the most significant nuclear incident since the Chernobyl disaster (1986).